**Exploratory Spatial Analysis of West Nile Virus Disease (WNV) in Franklin County**
**Research Thesis**

**Presented in partial fulfillment of the requirements for graduation**
***with research distinction*** **in Geographical Information Science Studies* in the undergraduate colleges of The Ohio State University**

**By**
**Mahmod Abdalla**

**The Ohio State University**
**April 2013**

**Project Advisor: Professor Ningchuan Xiao, Professor Morton O'Kelly and Desheng Liu**
**Department of Geography**

# Introduction

**West Nile virus** (WNV) is mosquito-borne arbovirus. The disease transmitted to people from the bite of an infected mosquito. It has been commonly found in humans, birds and other animals in Africa, Europe, Western Asia and the Middle East. The virus attacks the central nervous system causing symptoms ranging from fever and headaches to encephalitis, which can be potentially fatal. For most people, the risk of catching West Nile Virus is low. People over fifty and those with compromised immune systems are the most likely to display symptoms (2). In the U.S., the American Crow and the Blue Jay bird species became the main factors that contributed to the spread of the disease as infected birds travel from location to another location and mosquitoes transmit the parasite from them to other species. However, WNV disease was first identified in the West Nile sub region in the East African nation of Uganda in 1937. WNV disease has now spread globally, with the first case in the Western Hemisphere being identified in New York City in 1999; over the next 5 years, the virus spread across the continental United States, north into Canada, and southward into the Caribbean Islands and Latin America. WNV disease is now considered to be an endemic pathogen in Africa, Americas, Asia, Australia, the Middle East and Europe.

The year 2012 U.S., WNV disease is considered one of the worst epidemics. As of November 6, 2012, 48 states reported West Nile virus infections in people, birds, or mosquitoes. A total of 5,054 cases of West Nile virus disease in people, including 228 deaths, were reported to the Center of Disease Control (CDC). Of these, 2,559 (51%) were classified as neuroinvasive disease (such as meningitis or encephalitis) and 2,495 (49%) were classified as non-neuroinvasive disease.

The 5,054 cases reported in 2012 is the highest number (since 2003) of West Nile Virus disease cases reported to CDC through the first week in November. Almost 80 percent of the cases have been reported from 12 states (Texas, California, Louisiana, Mississippi, Illinois, South Dakota, Michigan, Oklahoma, Nebraska, Colorado, Ohio, and Arizona) and over a third of all cases have been reported from Texas.(1). The highest number of human cases reported in Ohio was 441 in 2002. On October 18, 2012, the **Ohio Department of Health reported 113 human cases of WNV in Ohio; two of these cases were in Franklin County. (2)**

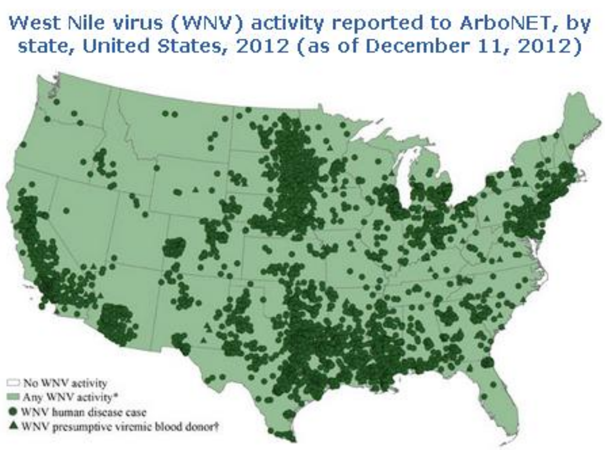



Figure1: Regions of prevalence.

## Initial Objectives

The main initial purpose of this research is to create maps that would help evaluate populations at risk of transmission of the WNV in selected cities and townships in Franklin County, Ohio.

The work plans to investigate three hypotheses:

- First, are moist land cover and vegetation contributing positively to the spreading of the WNV disease in the study area? There are different types of mosquito species that have varying levels of adaptation to the environment. In this hypothesis, I try to explore the correlation between "environment and land cover" and the prevalence of WNV (Interview).
- Second, is the increase in the host birds' (American Crows and Blue Jays) monthly populations an indicator of increasing expected transmission? Or, do the increase numbers of mosquitoes contribute the most to the prevalence of the WNV disease?
- Third, is the spread of the disease correlated to some areal-defined demographics? For example, are low income areas experiencing higher incidence rates compared to rich areas? The maps generated for this project will visualize all the disease incidents in humans and infected dead birds in these cities and townships. Also, I will map the mosquito trap locations to better understand the correlation between those factors.

## Practical Objectives

My original initiative objectives relied on the acquisition of suitable data that could enable conducting such research and thus examining the hypotheses mentioned above. My research was constrained by the lack of optimal data. The main data I wanted to use was human incidents with WNV infection in Franklin County. Unfortunately, the Franklin County Health Department (FCHD) authorities, the main source of data, could not provide any human infections incident rates due to the Health Information Privacy Act. These authorities collected a huge amount of data but have never used it for spatial analysis purposes. There is a gap between the data and the analysis. During an initial interview with Radhika Lyer, the epidemiologist and supervisor of the infectious disease program at the FCHD, I explained that this research would <u>not</u> use exact addresses of patients. The proposed work would geo-mask these addresses to conceal private information. However, this was not acceptable, because of regulations and privacy concerns.

As a second approach, in that same interview with Miss Lyer, I tried to obtain bird infection data that could have given some indication of the prevalence of the WNV. While they collect dead birds when residents called in for incidents, they stopped inserting this bird data in their database since 2003. This was because they consider birds are not one of the main factors of the WNV spread. This is a topic that could be subject to more careful analysis.

My third approach was to collect indirect data. I collected mosquito traps data from the FCHD. At this stage, I realized that I had to come up with other practical objectives due to the lack of suitable or proper data for the initial hypotheses. The obtained mosquito data since has information such as the dates of collection, addresses of traps and the testing of results (false or true).

I created new objectives which relate to my original research goals:

- My first and essential goal became examining the locations of mosquitoes’ traps.
- Where are those traps located? Do they follow a logical spatial distribution?
- What is the correlation between trap locations and population density areas?
- Does the time when those traps were processed indicate anything or are they evenly processed? If so, how many times a month?

- What is the correlation between those traps and vegetation/wetlands areas?
- By examining the infections of WNV in each trap location, which one has the highest infection number? Does comparing each year with the other years indicate anything?
- Also, I wanted to observe any patterns of infections during the mosquitoes' collection period between June and September. Does the output of this analysis point to some climate correlation or not?

## Data sources

To address these questions, I have used data from FCHD (point data) of mosquito traps. The data was created by collecting dead mosquito from traps that were constructed at certain addresses that are supposed to be spatially distributed around Franklin County. Furthermore, mosquitoes were collected from these traps as pools (1 pool = 50 mosquitoes) in June, July, August and September of the last four years (2009, 2010, 2011 and 2012). Then, each pool was tested for positive infection of WNV. In addition, I have used census group blocks from the 2010 United States Census. Finally, I have used population density, vegetation and wetland satellite images for more spatial interpretation.

## Data Collection

Data collection was the most tedious procedure during the research time. My original intention was to obtain humans (main factor), dead birds and mosquitoes' data. However, it turned out this task was not feasible at all because FCHD quit generating bird data since 2003 and refused to provide me with human incident data due to patient-privacy reasons. Even though this was ultimately unsuccessful, a lot of time was spent to set up an appointment with the epidemiology and environmental advisors. Even the mosquito trap location data, when it was received, was not directly suitable for geographical usage. My research then required creative work to make the best use of the data.

The problem was that the addresses for trap locations was not added to the original excel file; instead, they included a region of the cities, for example, north, south, etc. They then created a separate file in which they refer region to the exact address. It appears as though the FCHD authorities did not foresee geographical usage of their data.

## Data Processing

Since Humans and birds are the primary factors for my spatial analysis, I attempted to use human, birds and mosquitoes information. I managed to obtain a 2002 and 2003 hard copy data for all the three factors. I decided if I can transform this data to a digital format, I can conduct better analysis. I succeeded in converting the hard copy formats to a Microsoft Excel spreadsheet format. As I neared completion in this process, I found out that the data sample was small and it subsequently became difficult for me to incorporate in my research. In a way, this validates the concern with privacy reported by FCHD. The number of cases is simply so small that there is no way to make a broad or generalized conclusion, In fact these cases are rare, and when they do occur are likely to be front page news in the local paper (cite to Dispatch Article). As explained above, my topic therefore switched from an assessment of incidence, to a discussion of the apparent spatial sampling strategy.

Mosquitoes' traps locations data was obtained from FCHD for 2009, 2010, 2011, and 2012 (n=3648). Mosquitoes were collected from traps were set as polls ( poll = 50). Polls are not equal. So, if one infected mosquito were detected in a poll, then the poll is set to (true infection).

After some careful work and trial and error, data was geocoded for all observations. Remote sensing data was collected, which could assist analyzing the population density, vegetation and wetlands for FCHD. I obtained data from the natural resources conservation services of the United States Department of Agriculture USDA. This data was optimal for my spatial analysis.

## Methods and software steps

After I was done with processing and cleaning my data, I wanted to visualize it. I used a pivot table in excel to examine my mosquito trap data. The pivot table is also used to create summary tables and bar graphs.

I have used a tool called geocoding in the ArcGIS 10.1 software to convert addresses of mosquito's infected incidents' locations to geographical coordinate systems (latitude and longitude) to be able to map them. Also, I have used this software to overlay different layers on top of each other to create my final maps product.

I have used a software packages (SPSS) to further examine mosquitoes' trap locations in selected townships and cities in Franklin County. I was able to observe some interesting features through bar charts by using this software.

I have used a remote sensing image from USDA for Franklin County. I overlaid this image on top of my traps point layer to examine a potential correlation between population density and mosquitoes' traps location.

## Results

## A) Pivot Table

The pivot table enabled me to have a first look at the data. I was amazed with the output that generated from this table. First of all, Microsoft excel was used to consolidate the different spread sheet (2009, 2010, 2011, 20122) into one spread sheet that include all the four years. Then, pivot table was utilized to visualize data. By just looking at the grand total of true infections of WNV in each one of the four years in the research, it appeared clearly that 2010 was a peak year with 1599 incidents of WNV in mosquitoes. Table 1.

In the summary of the pivot table for the four years in the study period, the number of infections incidents correlated with the number of traps placed. For example, Columbus, Hilliard, Dublin and Grove City have the highest number of incidents and the highest number of traps constructed, with Columbus being the highest. This raises an interesting question: was the high number of traps constructed in these cities leading to an increase in the number of infections in mosquitoes? Or, is the increase in the number of mosquitoes resulting in a normal spread of the WNV disease? This is one of the many aspects of this disease that needs to be further studied.

Also, I created some bar graphs to visualize how the distributions of these infections of mosquitoes on each trap address look like. Also, another Bar graph was created to visualize which areas have enough traps and which need further considerations. The graphs presents an overall look of the disruption. Figure 2, 3.

Finally, by using a pivot table I was able to create a small table that has all the addresses of traps that have been constructed within Franklin County cities in the last four years (64 traps).

This table has the total number of infected mosquitoes. However, I have used it in ArcMap to create a map and it will be discussed in part number (c).

| **Sum of Mosquito_Count_Polls** | **Column Labels** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **FALSE** | | | | **FALSE Total** | **TRUE** | | | | **TRUE Total** | **Grand Total** |
| **Row Labels** | **2009** | **2010** | **2011** | **2012** | | **2009** | **2010** | **2011** | **2012** | | |
| **Bexley** | **0** | **0** | **0** | **0** | **0** | **24** | **28** | **36** | **22** | **110** | **110** |
| S Ardmore Rd | 0 | 0 | 0 | 0 | 0 | 24 | 28 | 36 | 22 | 110 | 110 |
| **Blacklick Estates** | | | | **0** | **0** | | | | **36** | **36** | **36** |
| Noe Bixby R | | | | 0 | 0 | | | | 36 | 36 | 36 |
| **Canal Winchester** | **2** | **0** | **1** | **0** | **3** | **32** | **57** | **45** | **31** | **165** | **168** |
| W Columbus s | 2 | | | | 2 | 32 | | | | 32 | 34 |
| Woodsview Dr | | 0 | 1 | 0 | 1 | | 57 | 45 | 31 | 133 | 134 |
| **Columbus** | **0** | **0** | **17** | **3** | **20** | **313** | **682** | **419** | **318** | **1732** | **1752** |
| Gerrard Ave | | 0 | | | 0 | 51 | 96 | | | 147 | 147 |
| Hess Blvd | | | | | | | | 36 | 31 | 67 | 67 |
| Merwin Rd | 0 | 0 | 1 | 0 | 1 | 20 | 61 | 39 | 27 | 147 | 148 |
| Mulford Rd | | | 0 | | 0 | 37 | 50 | 26 | 29 | 142 | 142 |
| Plainview D | | | 1 | 0 | 1 | | | 31 | 33 | 64 | 65 |
| Sale rd | 0 | 0 | | | 0 | 72 | 138 | | | 210 | 210 |
| Searles Ave | 0 | 0 | 0 | 0 | 0 | 37 | 53 | 37 | 22 | 149 | 149 |
| Sheringham | 0 | | 0 | 0 | 0 | 30 | 26 | 22 | 19 | 97 | 97 |
| Woodland Av | | | 2 | 0 | 2 | | | 46 | 23 | 69 | 71 |
| Alburn Dr | 0 | 0 | 0 | 1 | 1 | 41 | 65 | 42 | 31 | 179 | 180 |
| E Kanawha Av | | | 0 | 0 | 0 | | 75 | 45 | 40 | 160 | 160 |
| Mission Hill | 0 | | 1 | 0 | 1 | 25 | 61 | 40 | 25 | 151 | 152 |
| N Murray Hil | | 0 | 12 | 2 | 14 | | 57 | 55 | 38 | 150 | 164 |
| **Dublin** | **2** | **1** | **16** | **12** | **31** | **135** | **153** | **171** | **126** | **585** | **616** |
| Bidle ln | 0 | | 4 | 0 | 4 | 40 | 42 | 51 | 32 | 165 | 169 |
| Cruden Bay | 0 | 0 | 0 | 0 | 0 | 19 | 30 | 37 | 30 | 116 | 116 |
| Hawley Ct | 2 | 0 | 10 | 12 | 24 | 28 | 19 | 31 | 21 | 99 | 123 |
| Ruth Ann Ct | | 1 | 1 | | 2 | | 30 | 23 | | 53 | 55 |
| Sandy Ring | | | | 0 | 0 | | | | 19 | 19 | 19 |
| Sandy Rings | 0 | | | | 0 | 25 | | | | 25 | 25 |
| stonefence l | 0 | 0 | 1 | 0 | 1 | 23 | 32 | 29 | 24 | 108 | 109 |
| **Gahana** | **5** | **0** | **13** | **6** | **24** | **79** | **78** | **60** | **44** | **261** | **285** |
| Harrison Po | | | | | | 24 | | | | 24 | 24 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Skinner Ave | 0 | 0 | 2 | 0 | 2 | 23 | 29 | 25 | 22 | 99 | 101 |
| Mimosa Pl | 5 | 0 | 11 | 6 | 22 | 32 | 49 | 35 | 22 | 138 | 160 |
| **Galloway** | **3** | **0** | **1** | **0** | **4** | **83** | **99** | **64** | **49** | **295** | **299** |
| Birch Park | 1 | 0 | 0 | 0 | 1 | 23 | 39 | 32 | 23 | 117 | 118 |
| Leader Dr | 2 | 0 | 1 | 0 | 3 | 60 | 60 | 32 | 26 | 178 | 181 |
| **Grove City** | **0** | **2** | **28** | **9** | **39** | **60** | **23** | **203** | **131** | **417** | **456** |
| cenral ave | | | 25 | 9 | 34 | | | 48 | 28 | 76 | 110 |
| Mayflower C | | | 0 | 0 | 0 | | | 32 | 24 | 56 | 56 |
| Parkbrook D | | | 0 | 0 | 0 | | | 29 | 20 | 49 | 49 |
| Persimmon W | 0 | 2 | 2 | 0 | 4 | 24 | 23 | 34 | 20 | 101 | 105 |
| Tam Oshante | | | 1 | 0 | 1 | 36 | | 25 | 18 | 79 | 80 |
| Woodlawn Av | | | 0 | 0 | 0 | | | 35 | 21 | 56 | 56 |
| **Hilliard** | **0** | **1** | **8** | **5** | **14** | **115** | **178** | **119** | **141** | **553** | **567** |
| Darby Knoll | | | | 0 | 0 | | | | 17 | 17 | 17 |
| Darbyshire | 0 | 1 | 8 | 5 | 14 | 45 | 86 | 34 | 37 | 202 | 216 |
| Darley ct | | 0 | 0 | 0 | 0 | 37 | 50 | 33 | 26 | 146 | 146 |
| Drayton Rd | | 0 | 0 | 0 | 0 | | 42 | 23 | 25 | 90 | 90 |
| Wallington | 0 | | | | 0 | 33 | | | | 33 | 33 |
| Wynneleaf S | | | 0 | 0 | 0 | | | 29 | 36 | 65 | 65 |
| **Madison** | **0** | **0** | **0** | | **0** | **45** | **46** | **29** | | **120** | **120** |
| Newport ct | 0 | 0 | 0 | | 0 | 45 | 46 | 29 | | 120 | 120 |
| **New Albany** | **0** | **1** | **1** | **0** | **2** | **20** | **103** | **59** | **37** | **219** | **221** |
| Dobbins Dr | | 1 | 0 | 0 | 1 | | 62 | 34 | 20 | 116 | 117 |
| Dublin Gran | 0 | 0 | 1 | | 1 | 20 | 41 | 25 | | 86 | 87 |
| Johnstown R | | | | 0 | 0 | | | | 17 | 17 | 17 |
| **Obetz** | **0** | | | | **0** | **34** | **41** | | | **75** | **75** |
| Jermoore Rd | 0 | | | | 0 | 34 | 41 | | | 75 | 75 |
| **Reynoldsburg** | **0** | **0** | **6** | **0** | **6** | **48** | **82** | **88** | **62** | **280** | **286** |
| Daugherty D | | | 0 | 0 | 0 | | | 28 | 22 | 50 | 50 |
| Starlight D | 0 | 0 | 0 | 0 | 0 | 48 | 27 | 24 | 19 | 118 | 118 |
| Strouder Dr | | 0 | 6 | 0 | 6 | | 55 | 36 | 21 | 112 | 118 |
| **Upper Arlington** | **0** | **0** | **0** | **1** | **1** | **58** | **28** | **24** | **24** | **134** | **135** |
| Asbury Driv | | 0 | 0 | 1 | 1 | 31 | 28 | 24 | 24 | 107 | 108 |
| Avalon Rd | 0 | | | | 0 | 27 | | | | 27 | 27 |
| **(blank)** | | | | | | | **1** | | | **1** | **1** |
| Mission Hill | | | | | | | 1 | | | 1 | 1 |
| **Grand Total** | **12** | **5** | **91** | **36** | **144** | **1046** | **1599** | **1317** | **1021** | **4983** | **5127** |

Table 1: Pivot table summary. (True = infected, false = uninfected)

**2009 to 2012 WNV Mosquitoes' Infections**

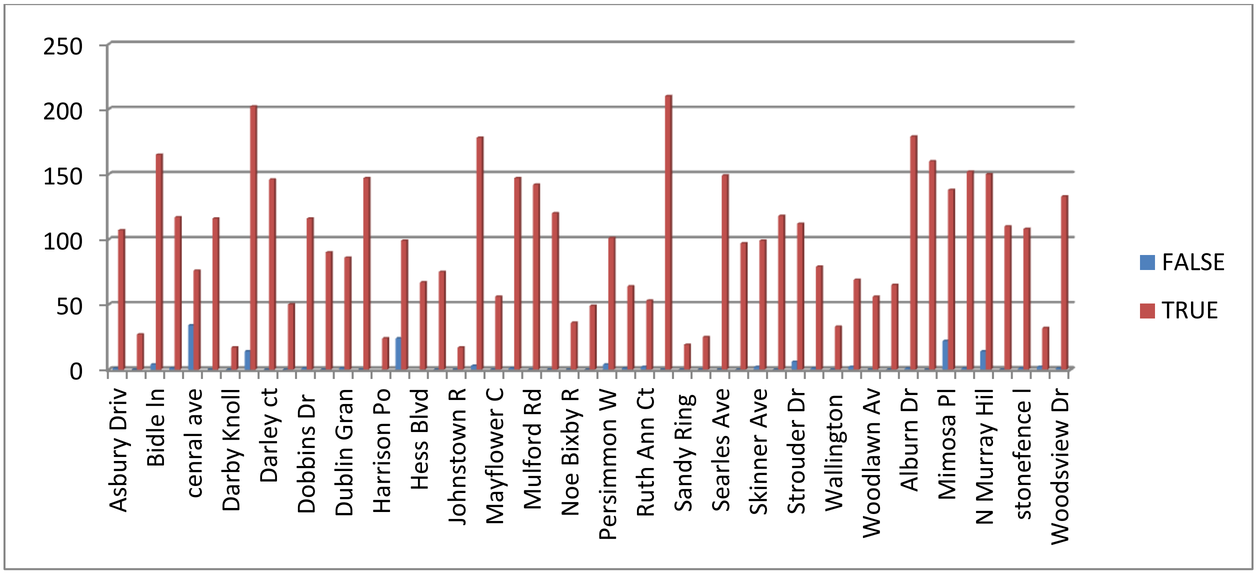



Figure2: Pivot table Bar graph. (True = infected, false = uninfected)

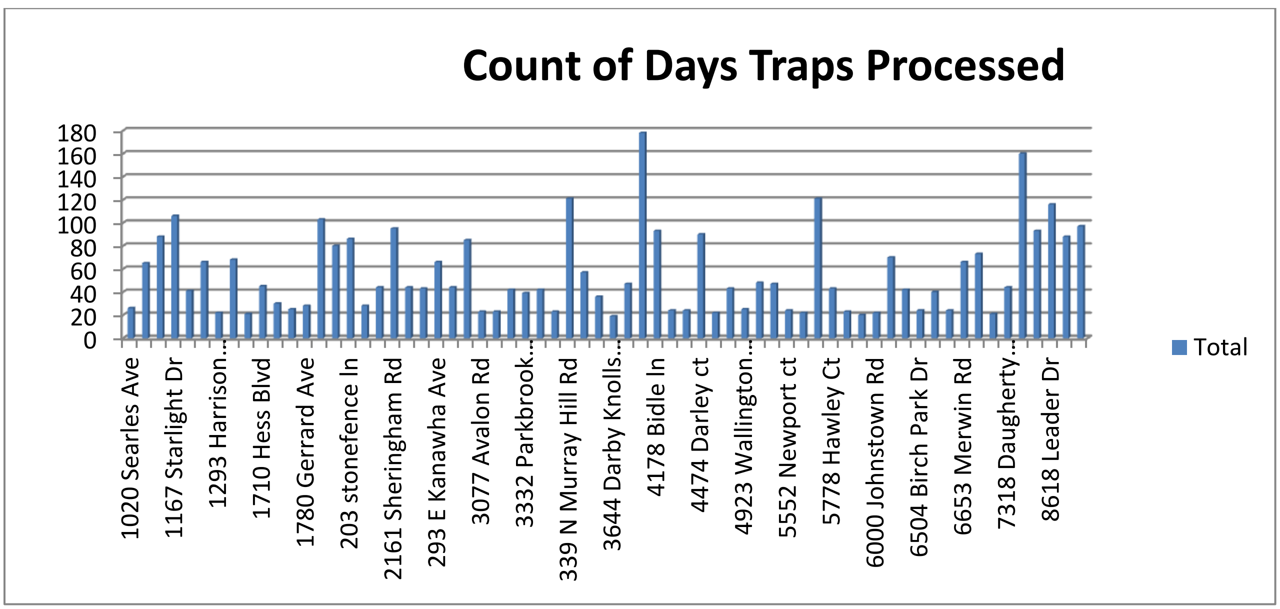



Figure 3: Pivot table Bar graph.

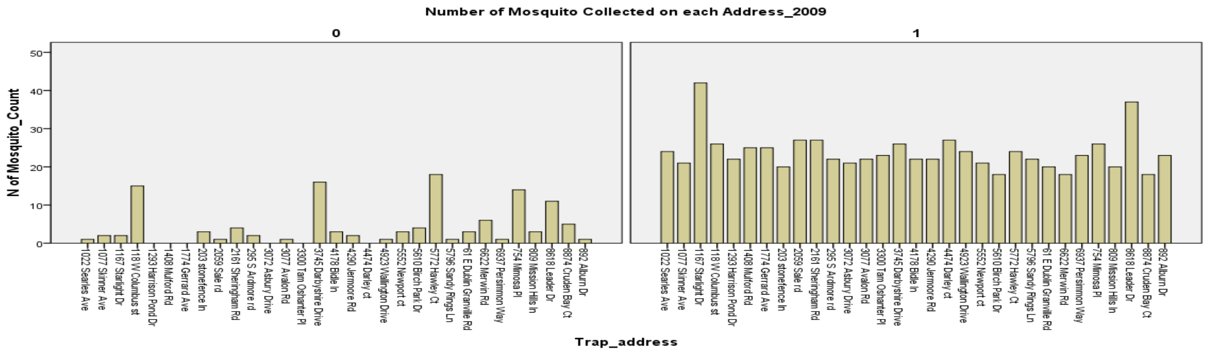
## b) SPSS

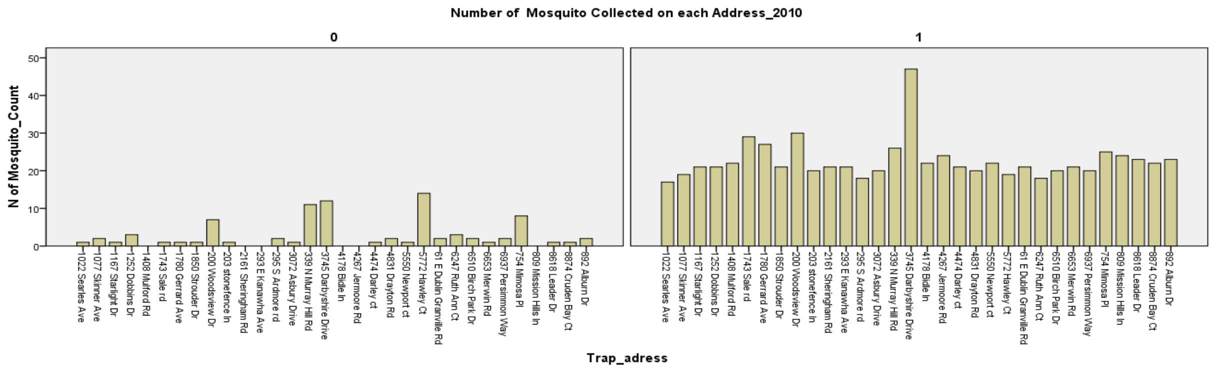
Since I was not content with the Excel diagrams, I have used different software called (SPSS) for better visualization. First, I have used it to create bar graphs for the number of mosquitoes collected on each trap. By just looking at the graphs, it appeared that the year 2009 has two outliers on the true side of the graph. Figure 3. Those two traps at ( 1167 straight and 8618 Leader) have a lot more infections than others in the same year. Also, 2010 has an extreme outlier, which is the trap constructed on (3745 Darbyshire drive) that made this trap the most infected one ever. Other than that, the distribution of the four years look almost the same.

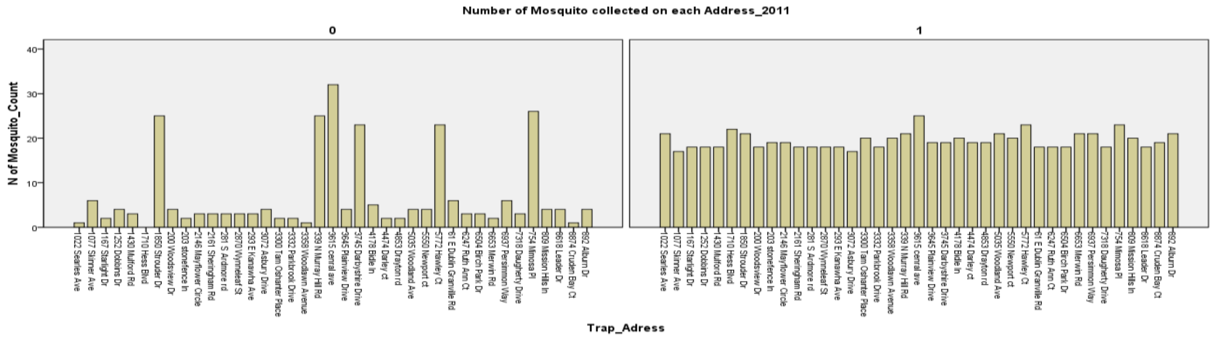
When I was looking at the false side of the graph on Figurre.4, I noticed that traps with the highest number of false infections are the same traps that have the highest nmber of true infections. This suggests that the increase in the number of infected mosquitoes means there exists human or animal cases around that trap because the WNV spreads in a cycle. Infected mosquitoes would transmit the virus to humans or animals; then, a healthy mosquito bites the infected human or animal and finally, the mosquito becomes infected. So, the high number of infecion in mosquitoes raises several questions.

Also, I have created other graphs by using SPSS to observe if there are any patterns of infections during the mosquitoes' collection period time between June and September for the four year period. I was trying to see if the output of this analysis point indicates some climate correlation or not. Unfortunately, I was not observing any pattern that could indicate any time-space problems. However, the trapped mosquitoes were not collected in a contiguous sequence time. Traps were processed at different dates within each month. Figure.5

*Number of Mosquito Collected on each Trap*



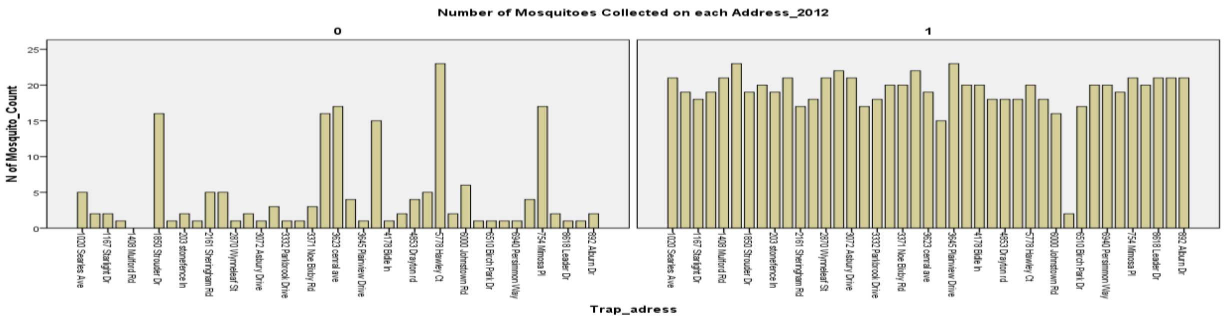
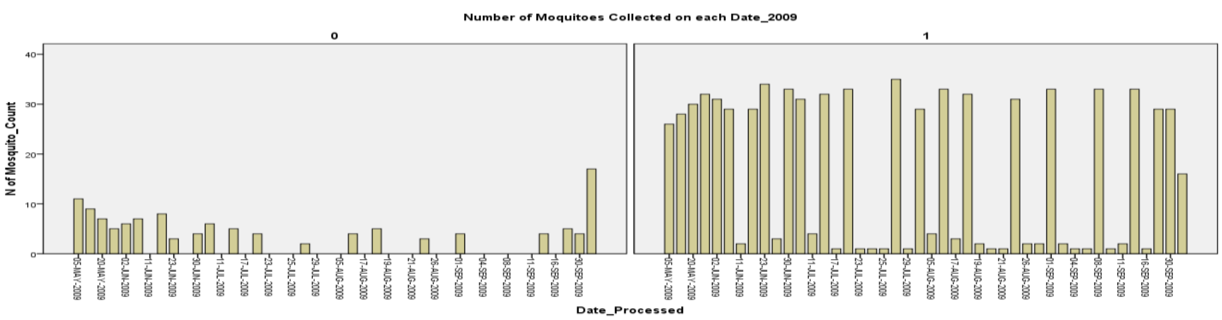
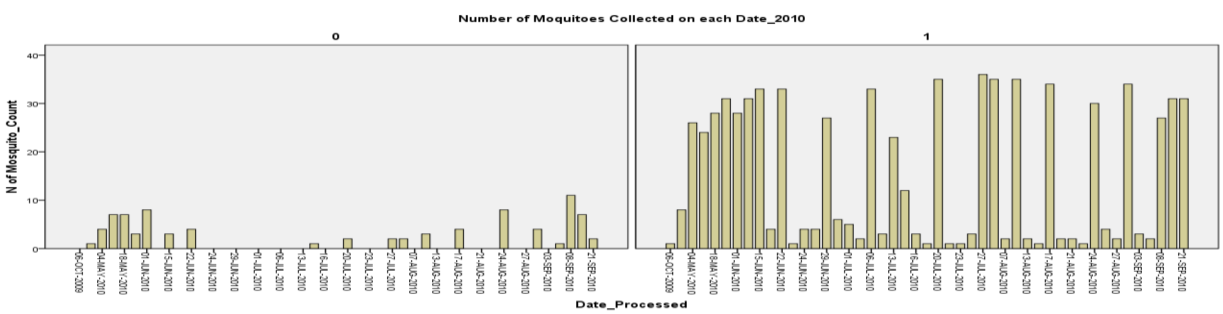



Figure4: SPSS Bar graphs for collected mosquitoes from adresses, (0 = Unhealthy mosquites, 1 = Healthy mosquites).

*Number of Mosquito Collected on each date*



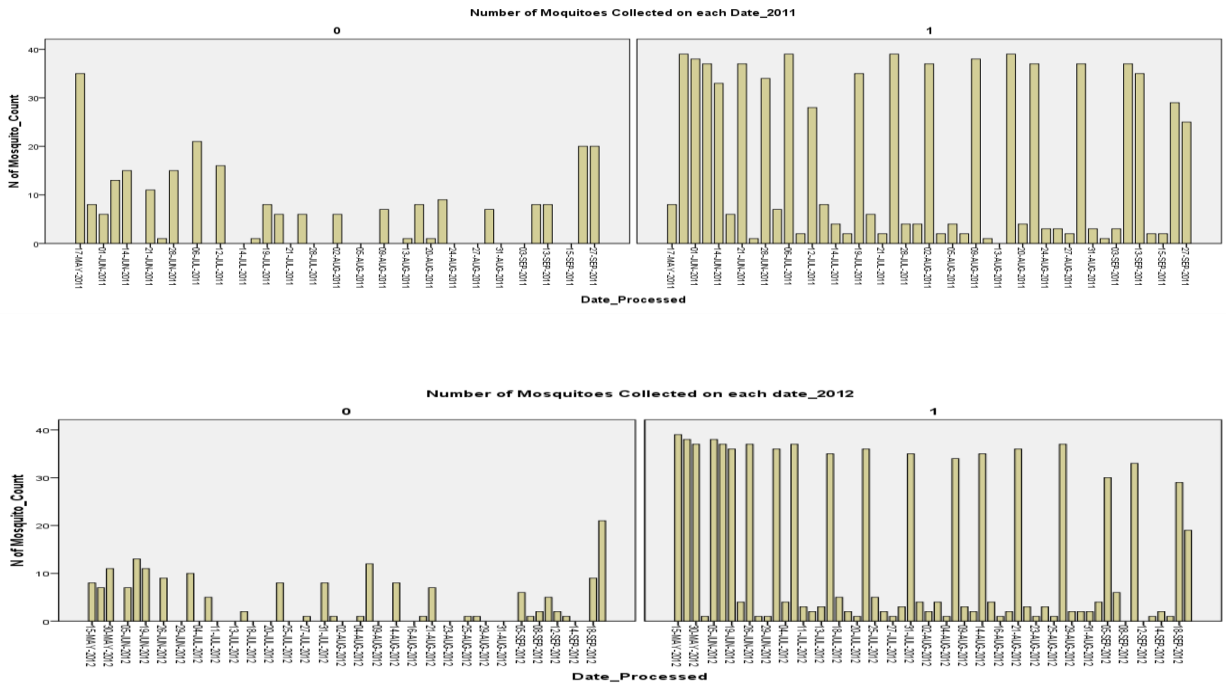



Figure5: SPSS Bar graphs for collected mosquitoes on different dates, (0 = Unhealthy mosquites, 1 = Healthy mosquites).

## c)ArcMap

After I geocoded all the addresses of mosquito traps locations, I overlaid the Census group blocks layer on top of it to have better visualization of locations. Then I overlaid the population density image on top of the first two layers. From the first look at the map, it was alarming that the majority of the traps appeared to be placed in low population density areas. It is obvious that if any person, with a minimaal knowledge of geography or statistics, would never locate those traps in these locations. I did not want to judge this map furthur as with figure 6, there were some issues with it. But what was the reason behind placing those traps in this low density area? I recalled a piece of information that was given to me by the FCHD suppervisor: Columbus City is not part of the FCHD and there is a different entity responsible for Columbus

City called the Columbus Health Department. So, those high density areas that appeared in figure 6 could be Columbus City as that makes much more sense.

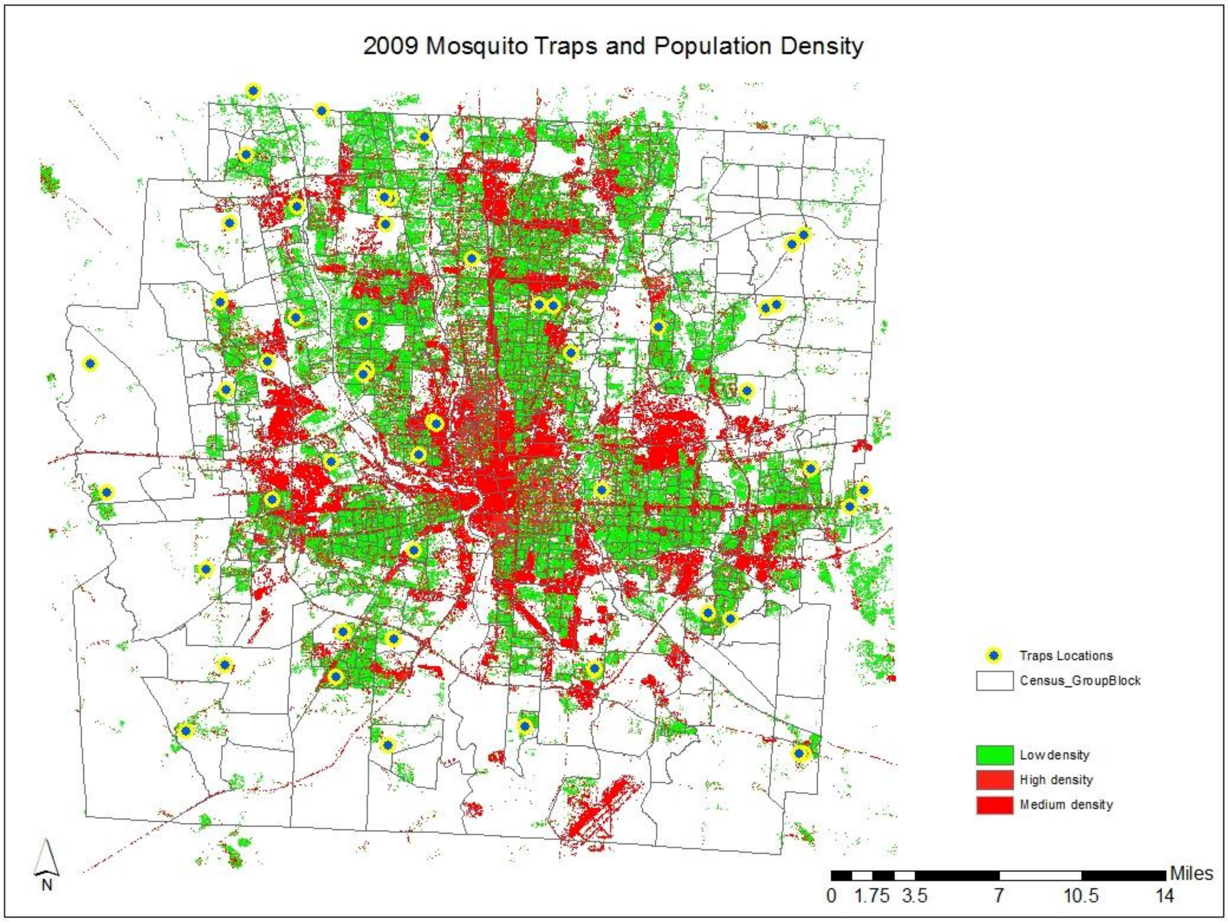



Figure.6: Mosquitoes' traps and population density including Columbus City.

To ensure that the reason traps were placed in low population density areas was because high population density areas were not part of the FCHD territory. First, I had to call the FCHD to verify this information. They supported my original thoughts about Columbus City. Then, to examine this, I overlaid the Columbus boundary layer on top of my previous map. From Figure.7, it patently appeared that FCHD authorities were constrained by the size of Columbus

City. Almost all of the high population density areas are located within the Columbus City boundary.

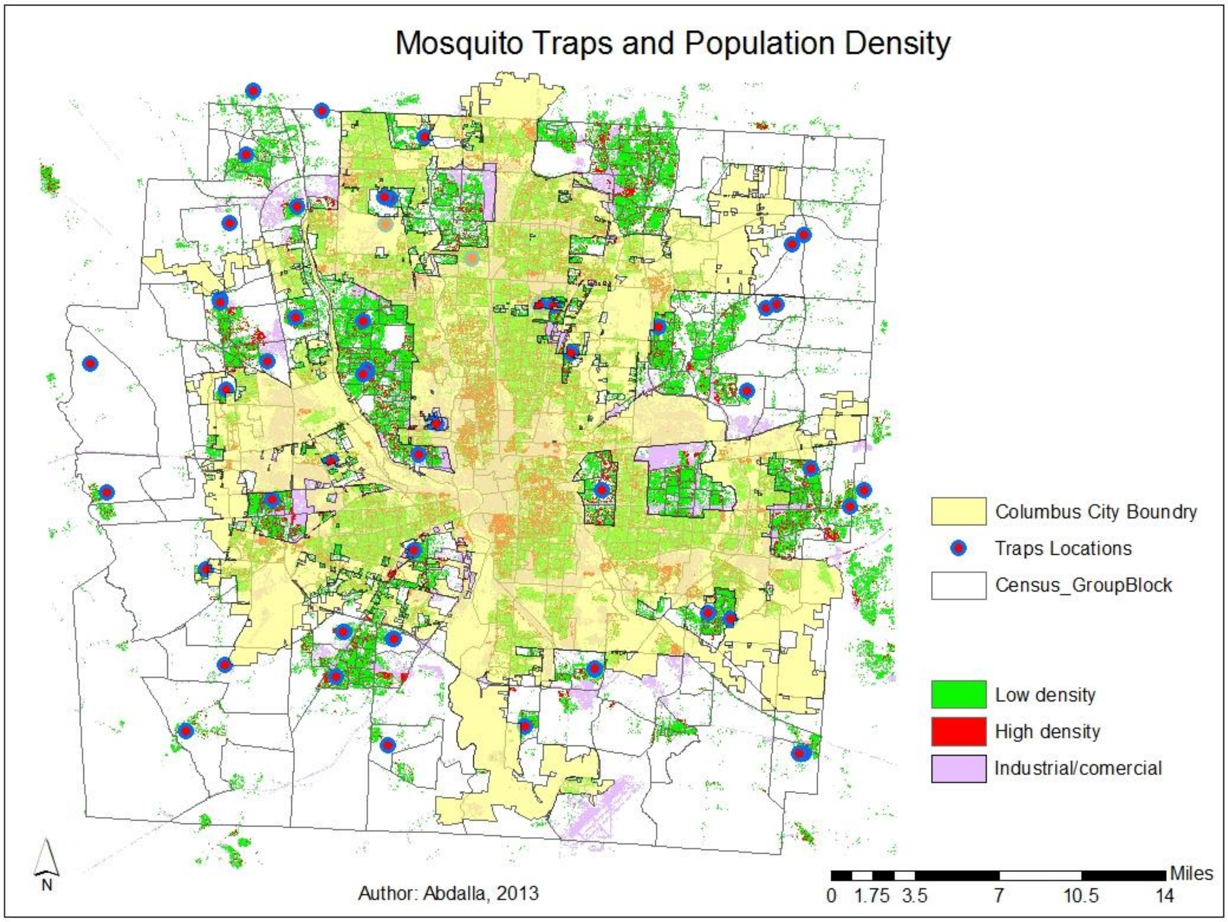



Figure.7 Mosquitoes' traps and population density excluding Columbus City

When I used the pivot table, I created a table that had all the mosquitoes' trap locations with the count of true cases in the four years. I cleaned up the table and imported it into ArcMap for geocoding. Then, I created a graduated symbols map to visulize vulnerable areas with the highest WNV infection. Apparently, Dublin, Hilliard, Grove City and Reynoldsburg have the highest number of infection. Figure.8

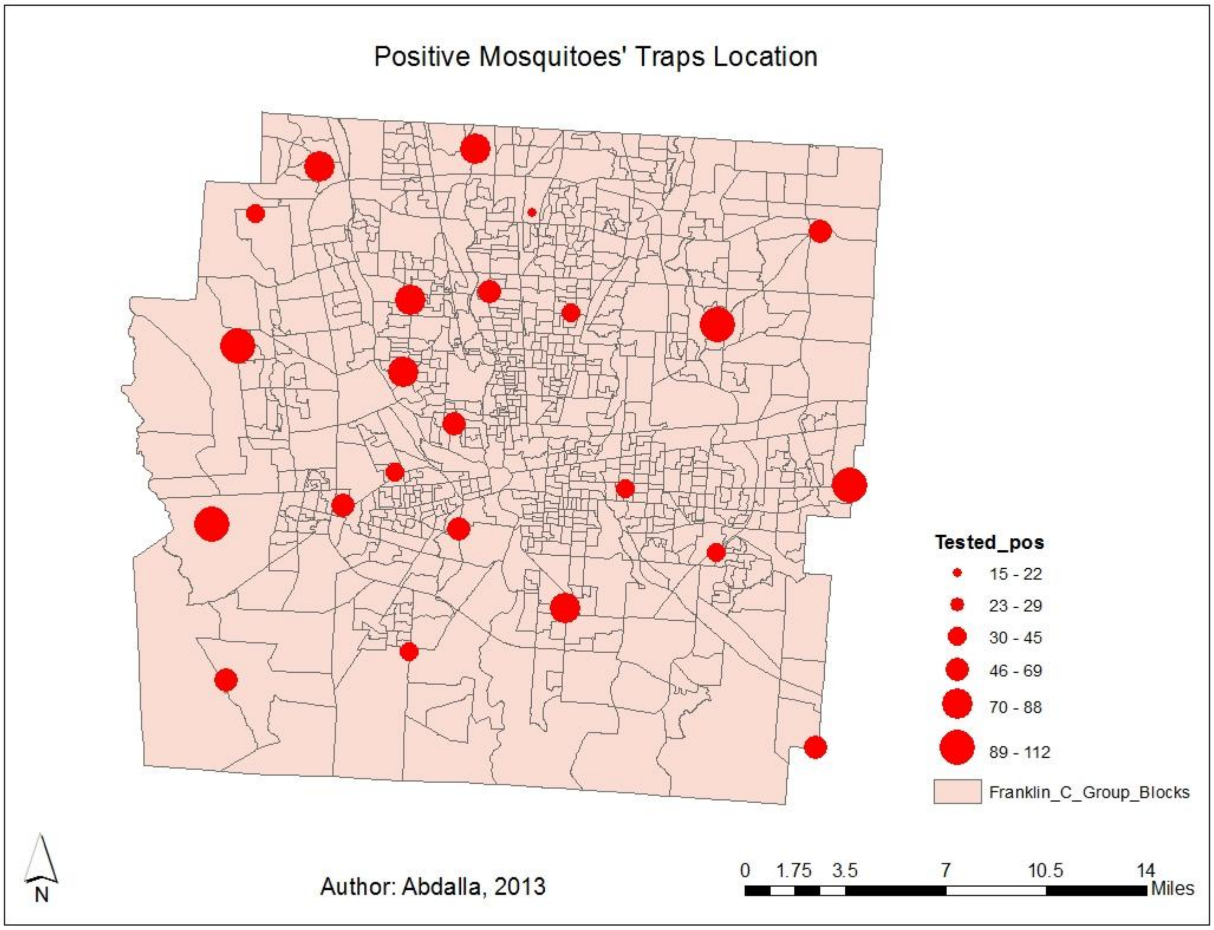



Figure 8. Magnitudes of positive mosquitoes' trap location

## Discussion and further study suggestions

With the availability of certain type of data, the research objectives were shifted to examine the spatial distribution of mosquitos' traps and their correlations with population density. From pivot table analysis, it appears that some cities have more mosquitoes' traps than other cities. For example, Dublin and Hilliard had traps that double the number of traps of any other city. When I observed this at the beginning, I thought that those cities had more people. I realized this was not true, Figure.7. What could be the reason? Are there more humans or bird incidents? With out Humans or birds data this question is hard to answer.

Another observation from the pivot table was that some of the traps have a significant number of trapped mosquitoes. Why is this the case? Is it the still water? Is it the undisposed trash? This is a responsibility of FCHD to balance the distribution of traps in each city. FCHD has to prioritize traps with the highest number of trapped mosquitoes in their battle against mosquitoes and prevent mosquito breeding by any means.

## Conclusion

In conducting this research as an undergraduate student, a unique experience was presented to me. It is not an easy task; rather, it is a process of several complicated tasks. My final output results are not what I was hoping to accomplish due to time limits and data collection and processing problems. However, I consider the study's final results to be worth my six months of effort, working diligently and patiently on this project.

I have learned that research is not necessarily the end to solving a problem but rather it is a mechanism to explain them. Through the process of conducting research, it has taught me how to be patient, persist in study and how to multitask projects. Also, research has deepened my knowledge and experiences in using different types of software and learning how to use new ones.

Another benefit of this research is the direct interaction with professors. I benefited from this opportunity the most in that I had the chance to sit down with my advisors and learn from their knowledge and personal thoughts about my research. They had enlightened my way through the whole process of my research period.

Finally, I believe I have gained a lot of new knowledge and experience by doing this research. Looking for data, processing data, interacting with my advisor and learning from them is no longer a daunting task that can not be handled. I am prepared to conduct further studies. I hope this study serves as the first steps for future study and research regarding West Nile Virus in Franklin County.

## References

*CDC,2012.“Fight the bite”* n.d. Web. 12 Nov. 2012. <http://www.cdc.gov/ncidod/dvbid/westnile/index.htm/>.

1. "Franklin County Public Health | Mosquito Management Program | Diseases." *Franklin County Public Health | Mosquito Management Program | Diseases*. N.p., n.d. Web. 13 Nov. 2012. <http://www.myfcph.org/mosq_diseases.php>.
2. Johnson, Brian J., Kristin Munafo, Laura Shappell, Nellie Tsipoura, Mark Roson, Joan Ehrenfeld, and Michael V. K.Sukhdeo. "The Roles of Mosquito and Bird Communities on the Prevalence of West Nile Virus in Urban Wetland and Residential Habitats." *Urban Ecosystem* (2012): 513-31. Web. 12 Nov. 2012. <http://www.springerlink.com/content/b44070h14824nw11/fulltext.pdf >.
3. Ghosh, Debarchana, Steven M. Manson, and Robert B. McMaster. "Delineating West Nile Virus Transmission Cycles at Various Scales: The Nearest Neighbor Distance–Time Model." *Cartography and Geographic Information Science* 37.2 (2010): 149-63. Print.
4. Ward, M. "Epidemic West Nile Virus Encephalomyelitis: A Temperature-dependent, Spatial Model of Disease Dynamics." *Preventive Veterinary Medicine* 71.3-4 (2005): 253-64. Print.
5. Ruiz, Marilyn O., Carmen Tedesco, Thomas J. McTighe, Connie Austin, and Uriel Kitron. "Environmental and Social Determinants of Human Risk during a West Nile Virus Outbreak in the Greater Chicago Area, 2002." *International Journal of Health Geographics* (n.d.): 1-11. International Journal of Health Geographics 2004, 3:8, 20 Apr. 2004. Web. 12 Nov. 2012. <http://www.ij-healthgeographics.com/content/3/1/8>.

6. Rios, Janelle, Carl S. Hacker, Christina A. Hailey, and Ray E. Parsons. "Demographic And Spatial Analysis Of West Nile Virus And St. Louis Encephalitis In Houston, Texas."*Journal of the American Mosquito Control Association* 22.2 (2006): 254-63. Print.

Non official references

1- Crane, Misti. "West Nile Virus Diagnosed in Second Franklin County Resident." *The Columbus Dispatch* [Columbus] 21 Aug. 2012: n. pag. Print.

2- Fernandez, Manny. "Dallas Copes With Unpredictability of West Nile Virus." *The New York Times*. The New York Times, 19 Sept. 2012. Web. 13 Nov. 2012. <http://www.nytimes.com/2012/09/19/us/unpredictability-in-dallas-west-nile-virus-outbreak.html?pagewanted=all>.